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Research on Direct Torque Control of Induction Motor Based on TMS320LF2407A

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Abstract

The direct torque control of Induction Motor is one of the high performance control system, which was proposed after the vector control scheme. During the recent 20 years, It has been developed rapidly for its concise system scheme, excellent dynamic and static performances. DTC system directly controls the electromagnetic torque and stator flux, using the analyzing method of space vector and stator flux orientation. This paper establishes the mathematical model of direct torque control (DTC) system of induction motor, and direct torque control (DTC) scheme of induction motor based on TMS320LF2407A is introduced. The control scheme gets the switch control signal of inverter with the space voltage vector modulation technology. Finally the approach has been implemented on DSP in a 1.1 kW drive. The results show that the DTC with SVPWM has many merits such as simple realization, good running performance and high voltage utilization ratio.

Keywords: TMS320LF2407A;SVPWM;direct torque control; induction motor;

1. Introduction

Induction motor Direct Torque Control (DTC) method has been developed rapidly for its concise system scheme, excellent dynamic and static performances. It solves some important problem in large degree that computing complexity in vector control, peculiarity changed by the impact of motor parameter, actual performance is difficult to achieve analysis result in theory. Direct torque control system adopts the method of space vector analysis and field orientation of stator flux, takes stator current and voltage through real-time detection to 3 / 2 transform, then directly the AC motor's torque and flux can be calculated in static α-β coordinate system. According to the result of controller output and location of the flux, look up optimal switch table, PWM signal can be generated. This paper establishes the mathematical model of direct torque control (DTC) system of induction motor. Then a realization scheme of fully digitized direct torque control system is introduced with TMS320LF2407A that works as the core control chip and IPM

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that works as main circuit. The control scheme obtains the switch control signal of inverter with the space voltage vector modulation technology. The system hardware and software structures are presented in this paper. The test results show that the DTC with SVPWM has many merits such as simple realization, good running performance and high voltage utilization ratio.

2. Control principle of Induction motor direct torque control and mathematical model

DTC system structure is shown in Figure 1, the main unit is constitute of rotate speed PI controller, torque PI controller , flux PI controller ,the observer of the stator flux linkage and the torque etc. In direct torque control system, how to control the stator flux linkage ψ_s is a key and it can be deduced by model U - I, the relationship between the stator flux linkage ψ_s and the voltage us are shown as follows. The control system adopts sub-circular flux linkage trajectory in low-speed operation, thus ensures the invariability of torque and flux linkage in low stator frequency.

DTC voltage equation is

$$\begin{cases} u_{s\alpha} = r_s i_{s\alpha} + p\psi_{s\alpha} \\ u_{s\beta} = r_s i_{s\beta} + p\psi_{s\beta} \\ u_{r\alpha} = r_r i_{r\alpha} + p\psi_{r\alpha} + \psi_{r\beta}\omega_r \\ u_{r\beta} = r_r i_{r\beta} + p\psi_{r\beta} - \psi_{r\alpha}\omega_r \end{cases} \tag{1}$$

Stator Flux equation is

$$\begin{cases} \psi_{s\alpha} = \int (u_{s\alpha} - r_s i_{s\alpha}) dt \\ \psi_{s\beta} = \int (u_{s\beta} - r_s i_{s\beta}) dt \end{cases} \tag{2}$$

$$|\psi_s| = \sqrt{\psi_{s\alpha}^2 + \psi_{s\beta}^2} \tag{3}$$

$$\theta = \arctan(\psi_{s\alpha} / \psi_{s\beta}) \tag{4}$$

In the formulas, $\psi_{s\alpha}$, $\psi_{s\beta}$ are Respectively the components of the stator flux linkage ψ_s in the α , β coordinate, θ is magnetic track phase angle., $u_{s\alpha}$, $u_{s\beta}$, $u_{r\alpha}$, $u_{r\beta}$ are stator and rotor voltage based on α、β axis and $i_{s\alpha}$, $i_{s\beta}$ are respectively the components of the stator current.

In the formula 5, the electromagnetic torque of the induction motor is shown.

$$T_e = \frac{3}{2} n_p (\psi_{s\alpha} i_{s\beta} - \psi_{s\beta} i_{s\alpha}) \tag{5}$$

Through formula (1) to (5), observation value of the stator flux and electromagnetic torque can be calculated. After getting calculation results, the stator flux and electromagnetic torque can be adopted closed-loop control and the control system's switch state can be got through space location of flux linkage and looking up switch table. When the inverter is on one of operation state, the flux trajectory moves along the direction of voltage vector that is corresponding to the state.

The estimation of the stator flux rely on the stator resistance, and the deviation of the stator resistance will cause the unreasonable deviation of the stator flux, in order to solve the problem that the performance of the direct torque control system is poor when the motor at the low speed, this paper puts forward the fuzzy controller with the fuzzy reasoning algorithm and it can estimate the stator resistance.

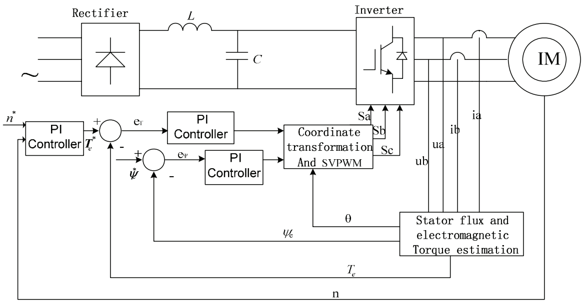


Fig. 1 the DTC system diagram based SVPWM

3. The composition of the system and current detection

The experiment system is built with the TMS320LF2407 as the control chip and the intelligent module PM200CAVJ060 as main circuit of the inverter. The hardware structure diagram of the system was shown in figure 2 with TMS320LF2407 as the master components, its instruction cycle is 25ns, with high resolution for PWM, and it can achieve complex calculation for real-time control. With two events management module EVA and EVB, It can achieve the 16 channel of the A/D conversion, symmetry and asymmetric PWM waves and dead zone programming etc. The chip HEDS - 5606 is used for speed detection, with the chip LF2407A for its frequency of the coded orthogonal pulse circuits by 4 times and with the timer for pulse counts, the feedback value of the speed can be obtained. The current sensor LA108-P is used for the stator current detection, A, B phase of the stator current signal is sampling, amplified and filter before sent to the A/D port of the DSP processor. The voltage sensor LV228P is used for the voltage detection, the value of the three-phase AC voltage can be obtained by measuring the voltage of the DC side in main circuit. the switching frequency of the power module PM200CAVJ060 Reach 20kHz, it constitutes of 6 IGBT units and it integrated perfect drive circuit in internal, so it can achieves the function of the over current protection, overheating protection and the low voltage protection for the system.

Current detection circuit is shown in fig.3.Since the motor windings are symmetrical, only two currents which are i_a and i_b are detected. As is shown in fig.3, the current i_a detected by the current Hall is sent to the signal amplification circuit and then to full-wave rectifier whose output is sent to the sampling pin ADCIN1 (i_b into ADCIN2) of A/D converter in TMS320LF2407A where the analog signal is converted to the digital to be processed.

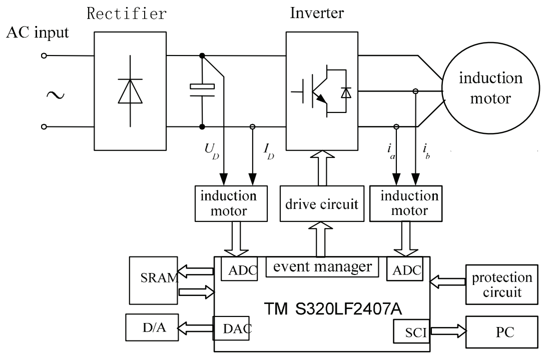


Fig. 2 The hardware structure diagram of the system

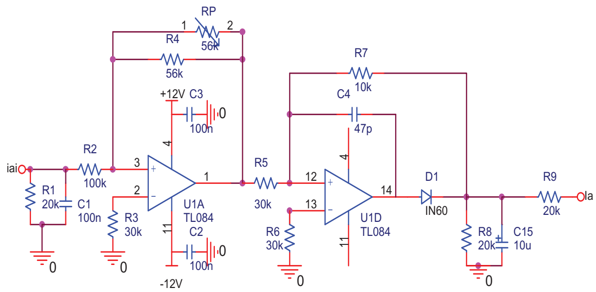
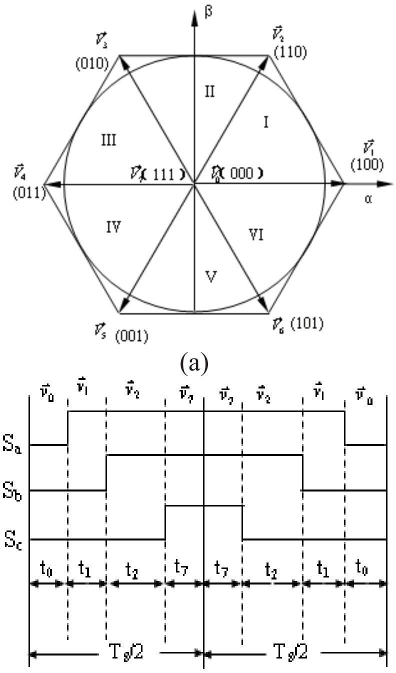


Fig.3 current detect circuit

4. Principle of SVPWM and Software design

Space voltage vector implementation of control system adopts space voltage vector modulation to form inverter switch signals. Its input signal is $V_{\alpha ref}$ and $V_{\beta ref}$ that is output signal of flux and torque controller. At any moment, stator voltage vector should fall on one of six-voltage sector that is derived from basic voltage vector distinction. In any PWM cycle T, discretional stator voltage vector can be synthesized through two adjacent basic vectors. As Fig4 shown, voltage vendor V_{ref} is in the first sector which is synthesized with two basic voltage vector V1, V2 and two Zero vector V7,V8 . The relation is:

$$
\begin{cases}
\mathbf{t}_1 = \dfrac{\sqrt{3}\left|\vec{\mathbf{v}}^*\right|\mathbf{T}_s\sin(\dfrac{\pi}{3}-\gamma)}{U_{\mathbf{dc}}} \\
\mathbf{t}_2 = \dfrac{\sqrt{3}\left|\vec{\mathbf{v}}^*\right|\mathbf{T}_s\sin\gamma}{U_{\mathbf{dc}}} \\
\mathbf{t}_0 = \mathbf{t}_7 = \dfrac{1}{2}(\mathbf{T}_s - \mathbf{t}_1 - \mathbf{t}_2)
\end{cases}
\tag{6}
$$



(b)

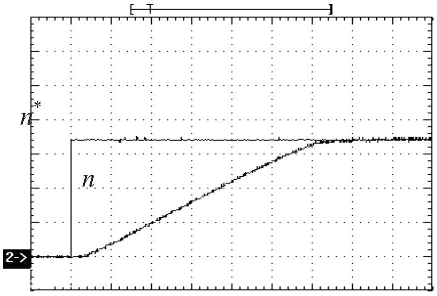
Fig. 4 Space vector PWM

Calculated steps of Space Vector as follows:(1)Voltage vector $\vec{v}^*$ compounded by calculation.(2)Judging it's phase according to $\vec{v}^*$ angle of the interval. (3) Calculating working time of switching voltage vector. (4) Compounding three-phase PWM signal according to working time of switch voltage vector.

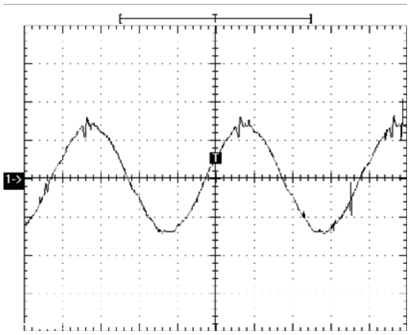
Control software is divided into two parts, main program and interrupted service program. The main program goes on cycle after completing the initialization. All control process is finished in the interrupted service program. The interrupted service program mainly performs the sampling of motor stator current and voltage, finishing the conversion of current, voltage, A / D converter, processing speed feedback signal through QEP unit, and output 6 channel PWM signals used to control based on direct torque control algorithms. The system adopts timer T3 to trigger interruption every a sample cycle, thus ensure to generate 6 channel PWM pulse.

5. Experimental results and conclusions

Experimental motor parameters is that power rating P_N is 1.1kW, stator rated voltage U_N is 380V, stator resistance rs is 3.66Ω, stator current is 2.66A,stator inductance Ls is 316.6mH, rotor inductance Lr is 316.6mH, stator mutual inductance Lm is 296.6mH, rated speed n_N is1410r/min. The experimental results are shown in Figure 5 to 8. From waves shown in these figures, transition time of the motor is short, the motor speed rises from 0 to 800 rpm in less than a second time, and there are no overshoot, which fully reflects excellent acceleration performance of the direct torque control. From figure 6 to 7, in steady-state current waveform and voltage waveform are sine wave with better quality.



Horizontal axis: 50ms/div
Vertical axis: 250rpm/div
Fig.5 setting rotational speed n* and practical rotational speed n



Horizontal axis: 10ms/div
Vertical axis: 1A/div
Fig.6 stator current wave in stable state

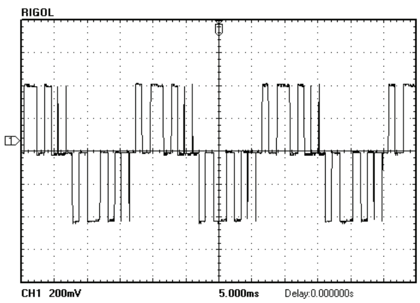
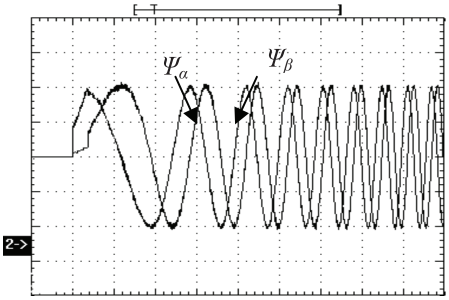


Fig.7 stator voltage wave in stable state



Horizontal axis: 50ms/div
Vertical axis: 0.4Web /div
Fig.8 α, β component of stator flux

The DTC scheme is studied in that using TMS320LF2407A DSP as the kernel of control system, and the software of control system complied in DSP assembly language. Stator flux observer is key part of DTC system. Classic U-I model is simple. However the integrator inevitably bring up the error accumulation on DC drift at a low speed. So this paper present a new model based on the transform between low speed and high speed.

In this paper, we study the application of TMS320F2407A in Direct Torque Control of Induction Motor System. Using SVPWM technology theory, harmonic is restrained by software design, signal generated is simple and convenient.

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